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LEUVEN

Radiation and antenna group
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Abstract

This presentation overviews the antenna activities at the KU Leuven, Leuven, Belgium. Each of the five general strategic research lines (EM theory, computational EM, antenna analysis and design, antenna fabrication, and antenna measurements) is described and substantiated by giving representative examples of the performed research and the obtained results. The largest activity is the design of innovating antenna radiators and systems for a multitude of different applications, for example beam steered antennas, wearable antennas, mm wave antennas, and antennas inspired by practical problems in industry. The most recent is the research activity on nano-antennas, which is performed in close operation with several physics departments worldwide.

Index Terms: research strategy, research lines, antenna design

Biography

Guy A. E. VANDENBOSCH received the M.S. and Ph.D. degrees in Electrical Engineering from the Katholieke Universiteit Leuven, Leuven, Belgium, in 1985 and 1991, respectively. From 1991 to 1993, he held a postdoctoral research position at the Katholieke Universiteit Leuven. Since 1993, he has been a Lecturer, and since 2005, a Full Professor at the same university. Guy Vandenbosch has taught or teaches courses on “Electromagnetic Waves”, “Antennas”, “Electromagnetic Compatibility”, “Electrical Engineering, Electronics, and Electrical Energy”, and ”Digital Steer- and Measuring Techniques in Physics”. His research interests are in the area of electromagnetic theory, computational electromagnetics, planar antennas and circuits, nano-electromagnetics, EM radiation, EMC, and bio-electromagnetics. His work has been published in ca. 265 papers in international journals and has led to ca. 360 papers at international conferences. Guy Vandenbosch has been a member of the “Management Committees” of the consecutive European COST actions on antennas since 1993. Within the ACE Network of Excellence of the EU (2004-2007), he was a member of the Executive Board and coordinated the activity on the creation of a European antenna software platform. At present, he leads the EuRAAP Working Group on Software and represents this group within the EuRAAP Delegate Assembly. From 2001 to 2007, he was the President of SITEL, the Belgian Society of Engineers in Telecommunication and Electronics. From 2008 to 2014, he was a member of the board of FITCE Belgium, the Belgian branch of the Federation of Telecommunications Engineers of the European Union. In the period 1999-2004, he was vice-chairman, in the period 2005-2009 secretary, and in the period 2010-2017 chairman of the IEEE Benelux Chapter on Antennas en Propagation. In the period 2002-2004 he was secretary of the IEEE Benelux Chapter on EMC. In the period 2012-2014, he was secretary of the Belgian National Committee for Radio-electricity (URSI), where he is also in charge of commission E. Guy Vandenbosch is a fellow of the IEEE. From September to December 2014, he was a visiting professor at Tsinghua University, Beijing, China.

KU Leuven in Belgium

TELEMIC research group

Katholieke Universiteit Leuven
ca. 60000 students

…

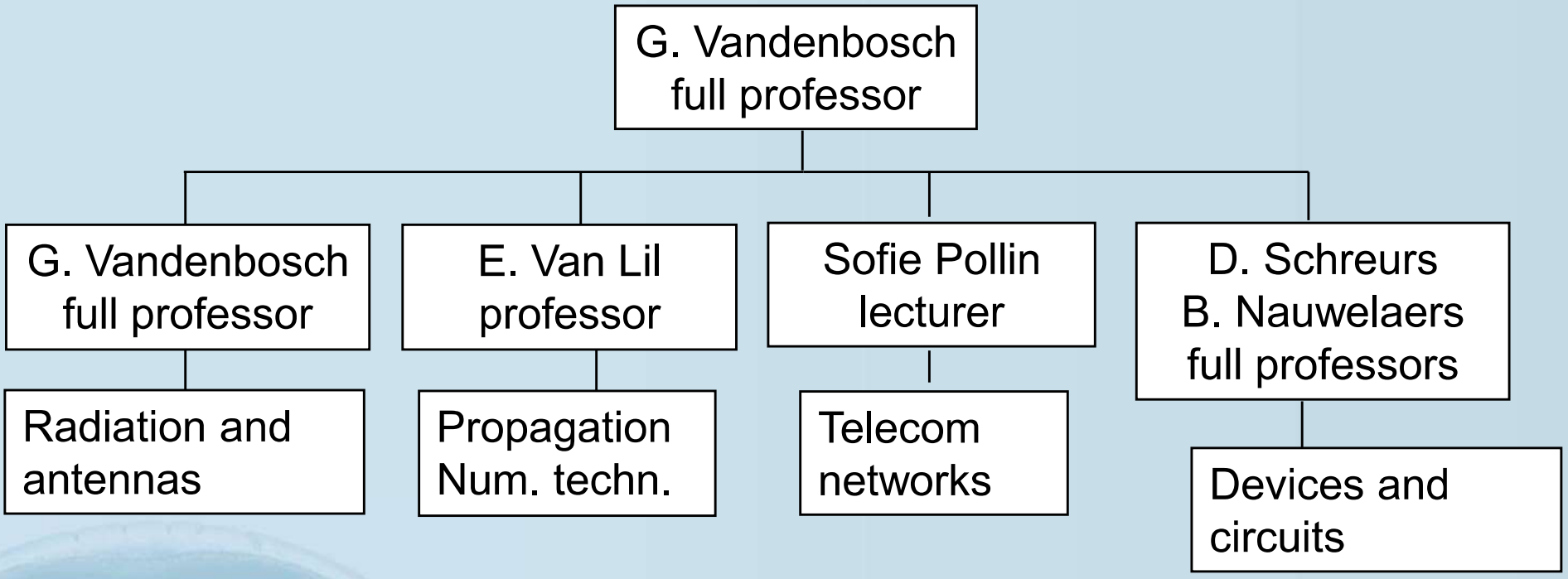
Faculty of Engineering Science
ca. 6000 students

…

Department of Electrical Engineering
ca. 400 Ph.D. researchers

Research group TELEMIC
ca. 40 Ph.D. researchers

TELEMIC research group



- radiation
- antennas
- antenna meas.
- EMC
- bio-electromagn.

- HF prop.
- troposph. prop.
- outdoor prop.
- indoor prop.
- adaptive antennas

- modeling
- performance anal.
- wired
- wireless

- measurements
- modeling
- design
- lin./non-lin.
- applications

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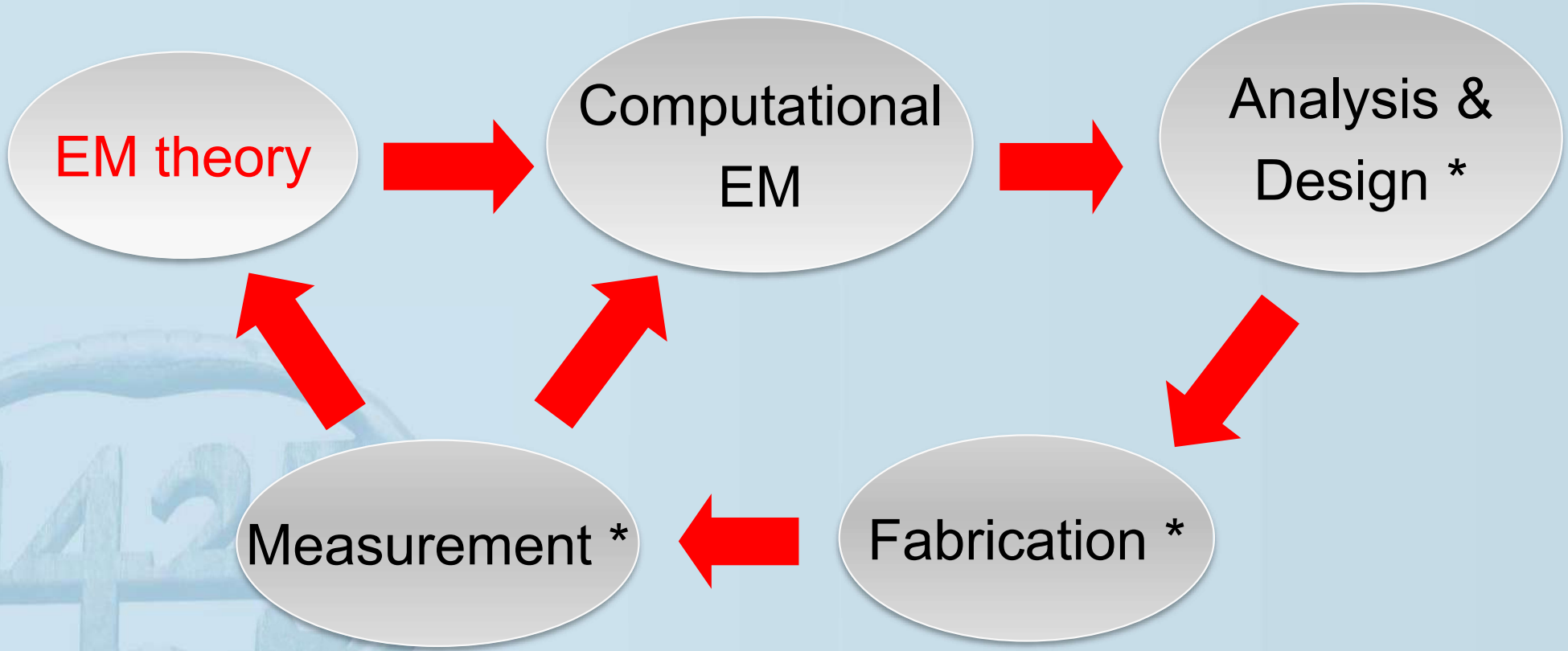
Strategic antenna research lines at KU Leuven

Radiation and antenna research

Fields of research and interactions



* cooperation with IMEC

EM theory: “hot” example

- Study of radiating structures
  - stored reactive energies
  - Q factors

Problem first considered in the late 1940’s

- Chu (1948)

Picked up in the 60’ and late 90’s

- Collin and Rothschild (1964)
- McLean (1996)

Stored energies: definition

- calculation of stored energy:
  - rather difficult, mainly due to the integral over entire space

$$W^e = \frac{1}{4}\int_V \varepsilon_m \mathbf{E}\cdot\mathbf{E}^* dV$$

$$W^m = \frac{1}{4}\int_V \mu_m^{-1} \mathbf{B}\cdot\mathbf{B}^* dV$$

entire space !!!

- calculation of power loss:
  - easy

$$P_{rad} = \lim_{S\to\infty} \oint_S \left(\frac{\mathbf{E}\times\mathbf{H}^*}{2}\right)\cdot d\mathbf{S}$$

Stored energies: new expressions !

$$\widetilde{W}^{e}_{vac} = \frac{1}{16\pi\omega^2\varepsilon_0}\left(\int_{V_1}\int_{V_2}(\nabla_1\cdot\mathbf{J}_1)(\nabla_2\cdot\mathbf{J}_2^*)\frac{\cos(k_0 r_{21})}{r_{21}}dV_1dV_2\right.$$

$$\left.-\frac{k_0}{2}\int_{V_1}\int_{V_2}(k_0^2(\mathbf{J}_1\cdot\mathbf{J}_2^*)-(\nabla_1\cdot\mathbf{J}_1)(\nabla_2\cdot\mathbf{J}_2^*))\sin(k_0 r_{21})dV_1dV_2\right)$$

$$\widetilde{W}^{m}_{vac} = \frac{1}{16\pi\omega^2\varepsilon_0}\left(k_0^2\int_{V_1}\int_{V_2}(\mathbf{J}_1\cdot\mathbf{J}_2^*)\frac{\cos(k_0 r_{21})}{r_{21}}dV_1dV_2\right.$$

$$\left.-\frac{k_0}{2}\int_{V_1}\int_{V_2}(k_0^2(\mathbf{J}_1\cdot\mathbf{J}_2^*)-(\nabla_1\cdot\mathbf{J}_1)(\nabla_2\cdot\mathbf{J}_2^*))\sin(k_0 r_{21})dV_1dV_2\right)$$

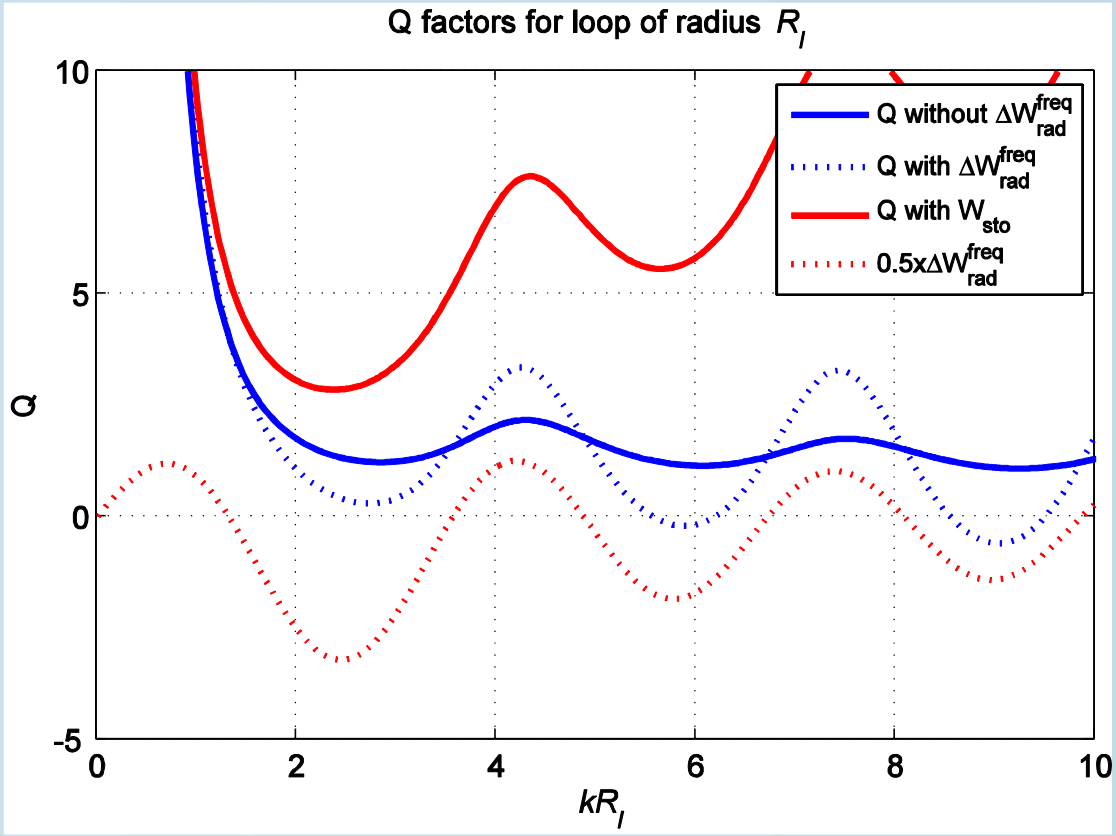
- rigorous, general
- simple to interpret, easily implemented
- no dependency on coordinate system
- no derivatives

G. A. E. Vandenbosch, Reactive energies, impedance, and Q factor of radiating structures, *IEEE Trans. Antennas & Propagat.*, Vol. 58, No. 4, April 2010.

But … negative stored energies ???

Q for loop with constant current

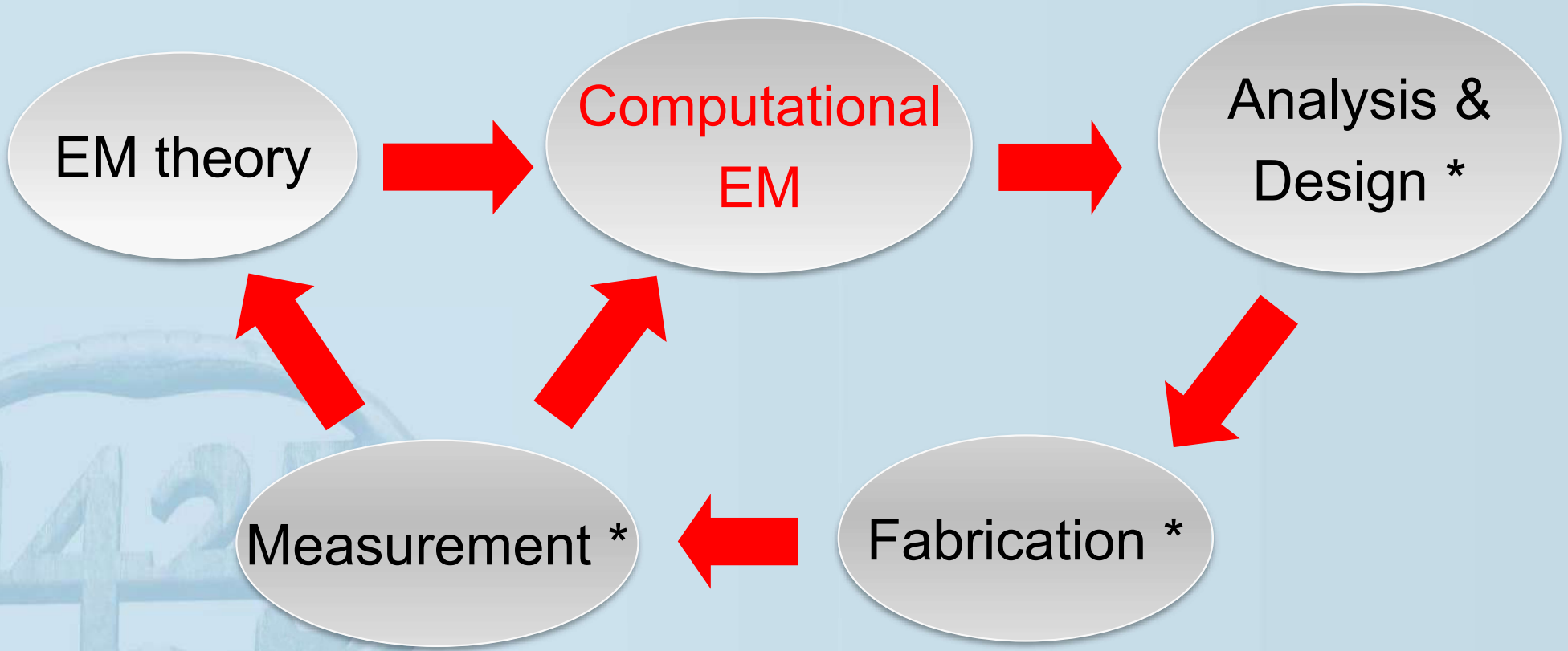
G. A. E. Vandenbosch, Radiators in time domain, part II: finite pulses, sinusoidal regime, and Q factor, *IEEE Trans. Antennas & Propagat.*, Vol. 61, No. 8, August 2013.



problem is still not completely solved …

Radiation and antenna research

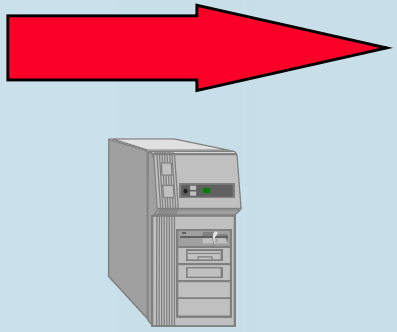
Fields of research and interactions



* cooperation with IMEC

Computational EM

physical structure
(antenna, circuit, PCB, human body)

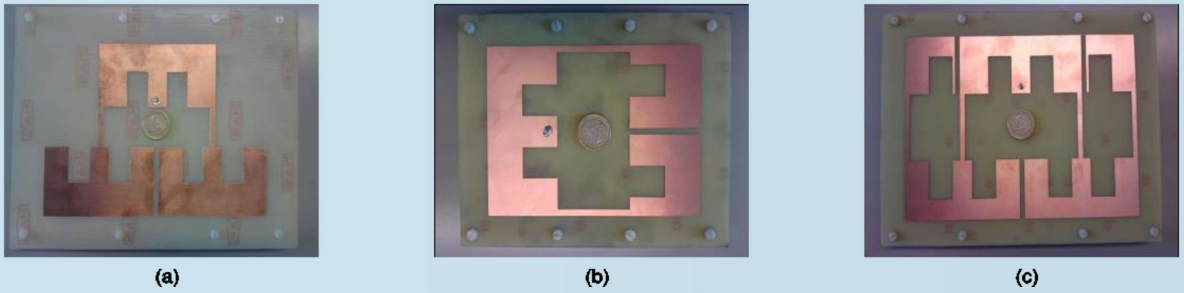


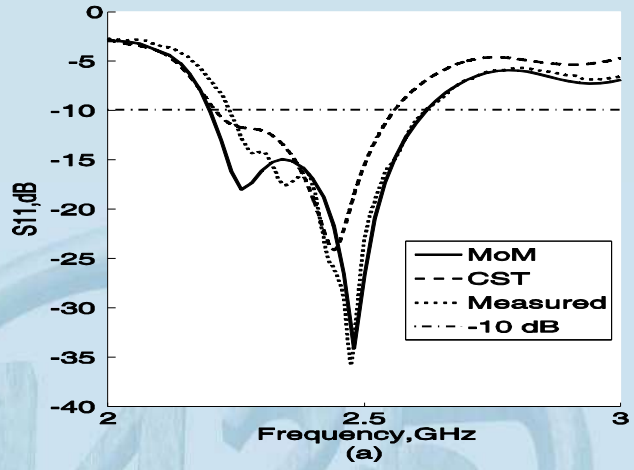
relevant parameters
(radiation, impedances, temperature)

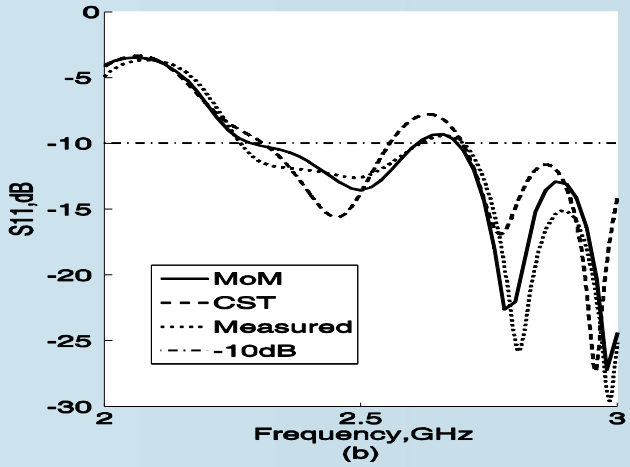
- in-house developed solver **MAGMAS**
  - Model for the Analysis of General Multilayered Antenna Structures
  - long-term fundamental research line since 1985, ca. 50 person years
  - is used in many (antenna) projects as basic analysis and design tool
  - extended to cover niche needs that commercial solvers do not handle

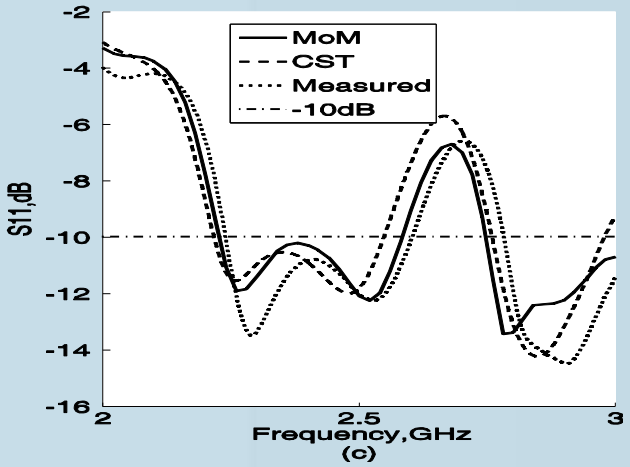
MAGMAS: example of structure

Strongly coupled small arrays with highest reported aperture efficiency







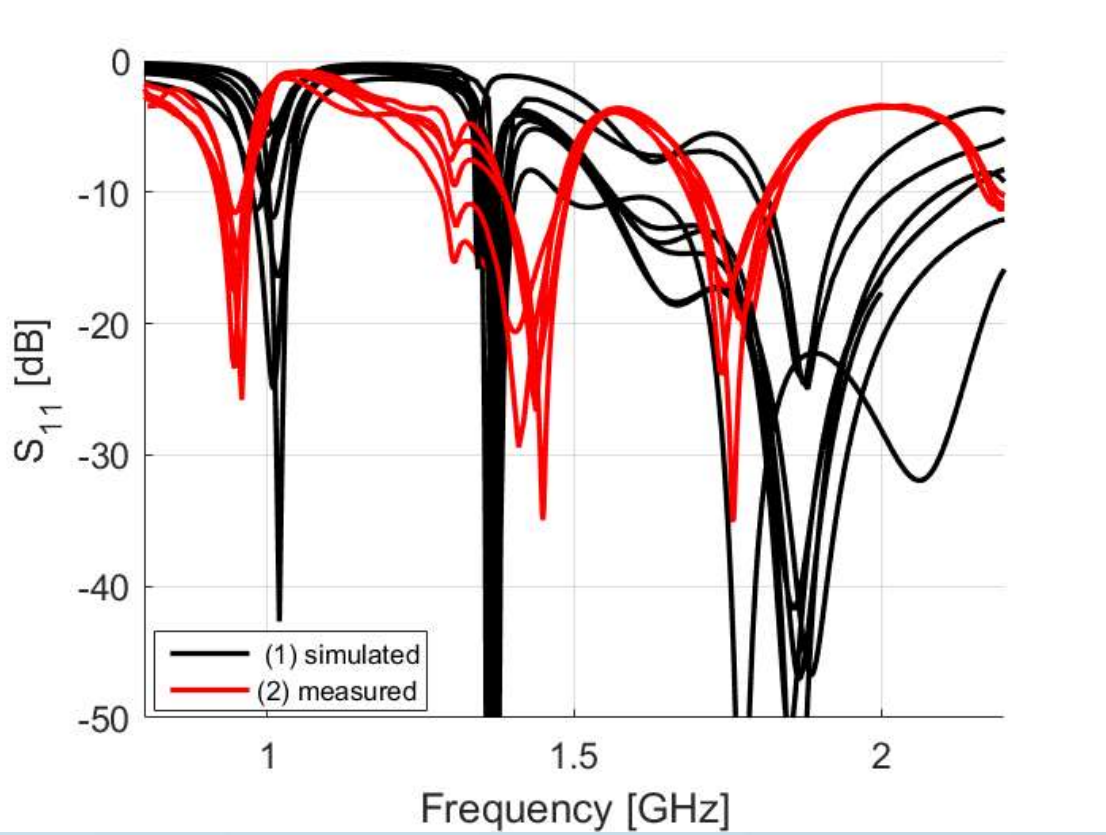


Z. Ma and G. A. E. Vandenbosch, Low-cost wideband microstrip arrays with high aperture efficiency, *IEEE Trans. Antennas & Propagat.*, Vol. 60, No. 6, June 2012.

MAGMAS: upgrades

- **Time domain**
  - Z. H. Firouzeh et al., “Transient scattering by infinite conducting cylinders with arbitrary cross section using time domain integral equations ”, IET Microwaves, Antennas & Propagation, subm. Jan. 2011.
- Hybridization with Finite Elements Technique
- Green’s functions
  - very thin layers
  - layers with complex tensor characterization
    - Plasma, uniaxial, bi-anistropic, chiral, …
  - Z. H. Firouzeh, G. A. E. Vandenbosch, R. Moini, S. H. Hedam Sadeghi, and R. Faraji-Dana, “Efficient evaluation of Green’s functions for lossy half-space problems", Progress In Electromagnetic Research, Vol. 109, 2010.
- New components
  - Inclined wall, thick ground plates, …
- Fast inversion techniques
- …

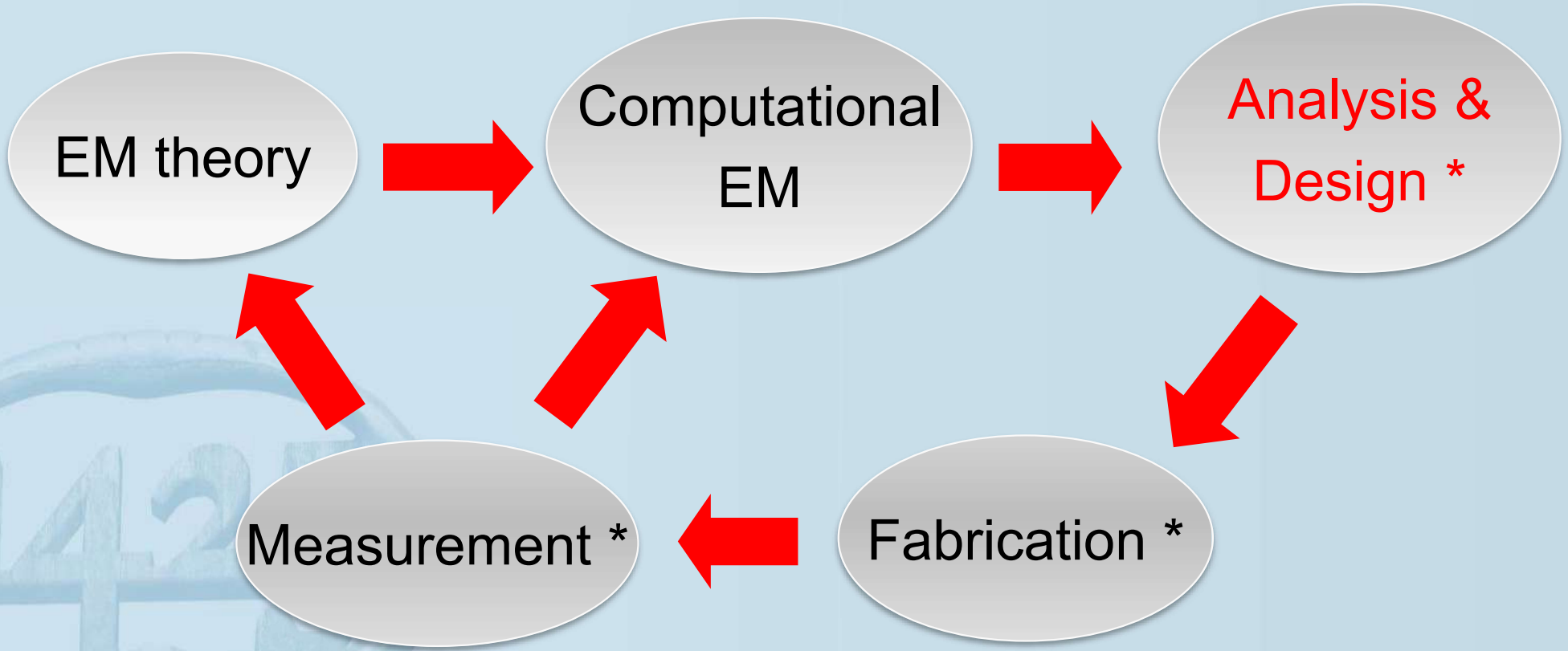
Benchmarking: EuRAAP WG Software



G. A. E. Vandenbosch, F. Mioc, M. Saporetti, and L. Foged, "Bridging the Simulations – Measurements Gap: State-of-the-Art", Antennas and Propagation Magazine, Vol. 58, No. 6, pp. 12-24, Dec. 2016

Radiation and antenna research

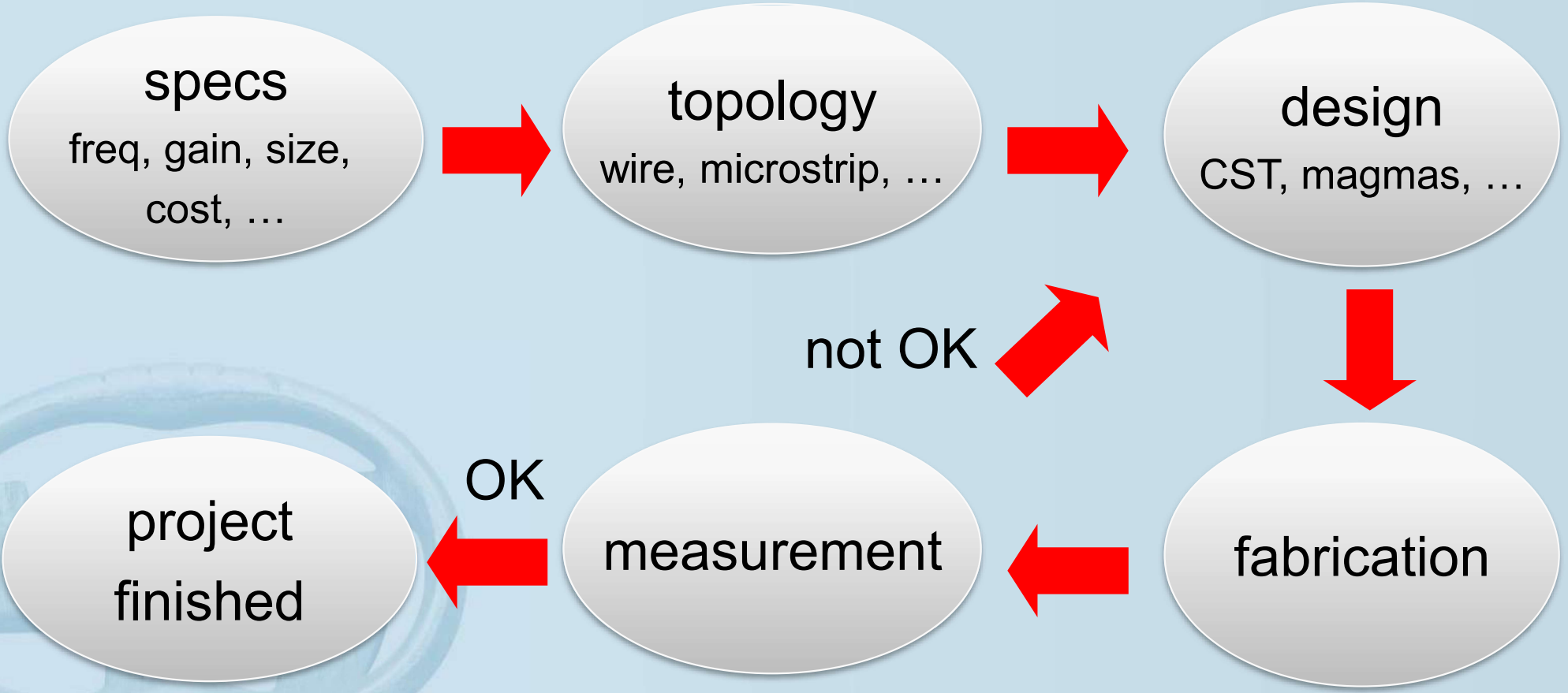
Fields of research and interactions



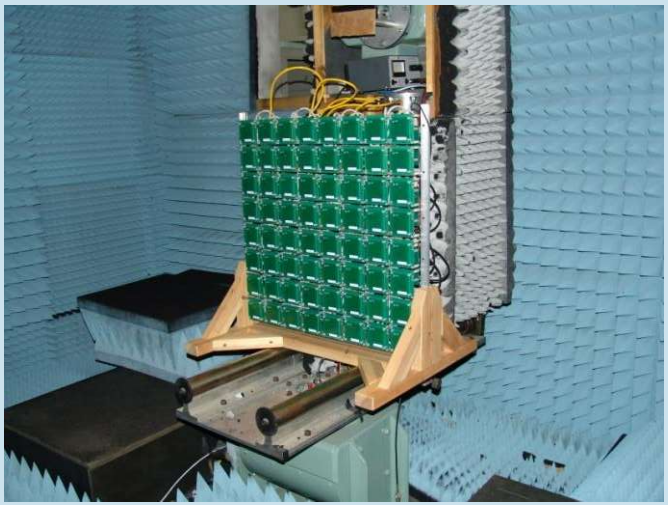
* cooperation with IMEC

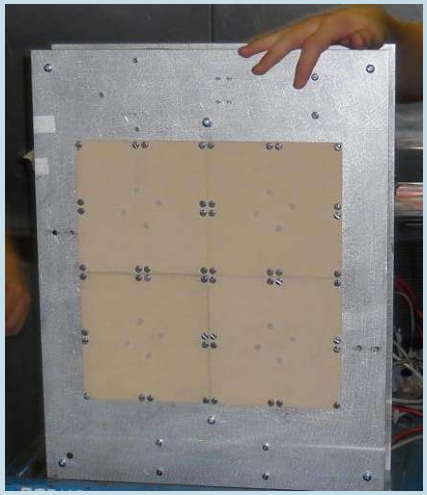
Antenna design @ TELEMIC

- for research purposes
- for industry



Antenna design: electronic beam steering





8 x 8 array with analogue electronic beam steering

W. Aerts, P. Delmotte, and G. A. E. Vandenbosch, "Conceptual study of analog baseband beam forming: design and measurement of and eight-by-eight phased array", IEEE Trans. Antennas Propagat., June 2009.

4 x 4 array with digital electronic beam steering

H. Aliakbarian, E. Van der Westhuizen, R. Wiid, V. Volski, R. Wolhuter, G. A. E. Vandenbosch, and P. Coppin, A digitally beam-steerable antenna array system for positioning-based tracking applications, IEEE Antennas Propagat. Magazine, Dec. 2013.

Challenges: architecture, COTS components, cost, …

MUBTS: Multiple User Beam Tracking System

Complete communication system with
- 8 x 2 array with digital electronic beam steering
- tracking capabilities for up to 4 users
- full communication capabilities: images, data
- with demonstration software and GUI

H. Xu, H. Aliakbarian, and G. A. E. Vandenbosch, Off-the-shelf low-cost target tracking architecture for wireless communications, IEEE Systems Journal, Vol. 9, No. 1, March 2015.

H. Xu, H. Aliakbarian, E. Van der Westhuizen, R. Wolhuter, and G. A. E. Vandenbosch, “An architectural scheme for real-time multiple users beam tracking systems”, IEEE Systems Journal, accepted 10 July 2014.

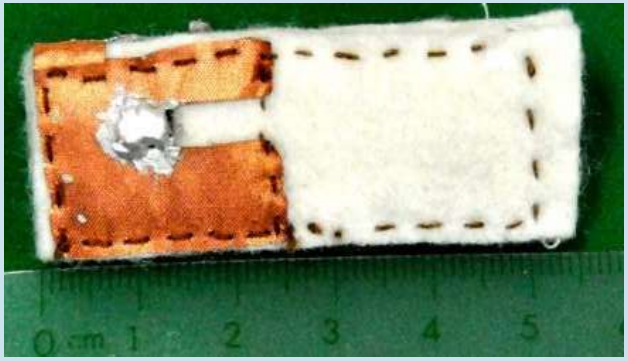
Antenna design: wearable antennas

- **Challenges:**
  - Coupling between human body and antenna
  - Various deformations and different operating environments
  - Large fabrication tolerances, inaccurate material properties
  - Low profile, light weight, comfortable to wear,…
- **Fabrication:**
  - Cut felt substrate and patch by hand / laser
  - Heat and paste with iron
  - Metallic threads for vias
  - Low temperature solder or metallic glue for the connector

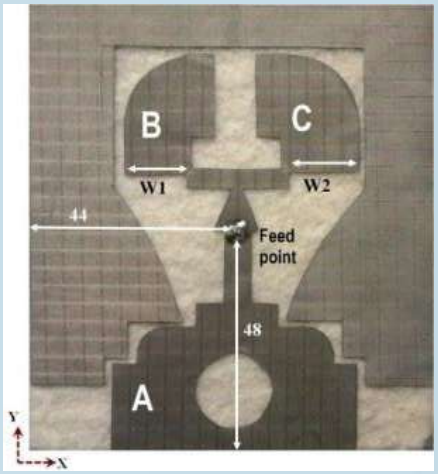
S. Yan, P.J. Soh and G.A.E. Vandenbosch, "Wearable dual-band composite right/left -handed (CRLH) waveguide textile antenna for WLAN applications," *Electronics Letters*, vol. 50, no. 6, pp. 424-426, Mar. 2014. (*Color Feature*)

Antenna design: wearable antennas

- **Feature: Wideband wearable antennas with full ground**



Broadband textile antenna for WBAN

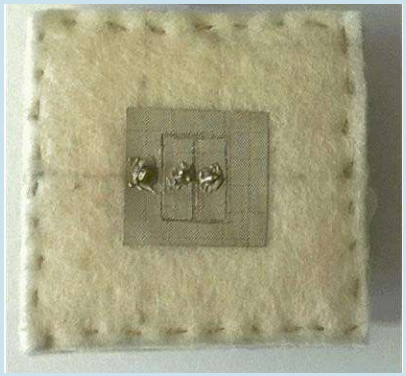


First all-textile UWB antenna with full ground plane

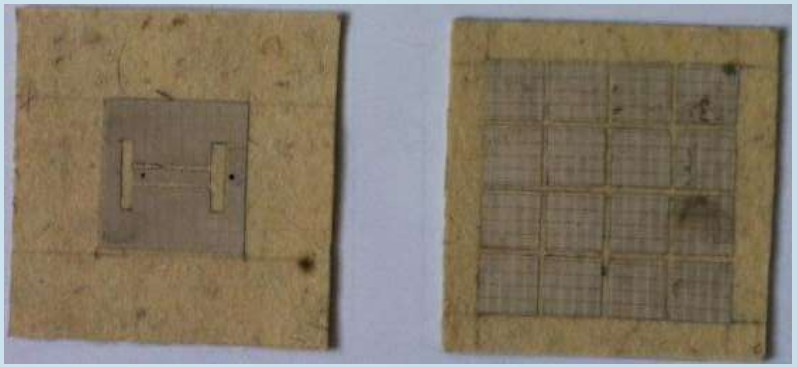
Left figure: P. J. Soh, G. A. E. Vandenbosch, S. L. Ooi, H. M. R. Nurul, "Design of a broadband all-textile slotted PIFA", IEEE Trans. Antennas Propagat., Vol. 60, No. 1, Jan 2012.
Right figure: P. B. Samal, P. J. Soh, and G. A. E. Vandenbosch, "UWB All-Textile Antenna with Full Ground Plane for Off-Body WBAN Communications", IEEE Trans. Antennas Propagat., Vol. 62, No. 1, Jan. 2014.

Antenna design: wearable antennas

- **Feature: Wearable antenna design involved with Metamaterials**



Dual-band patch loaded with CRLH TL



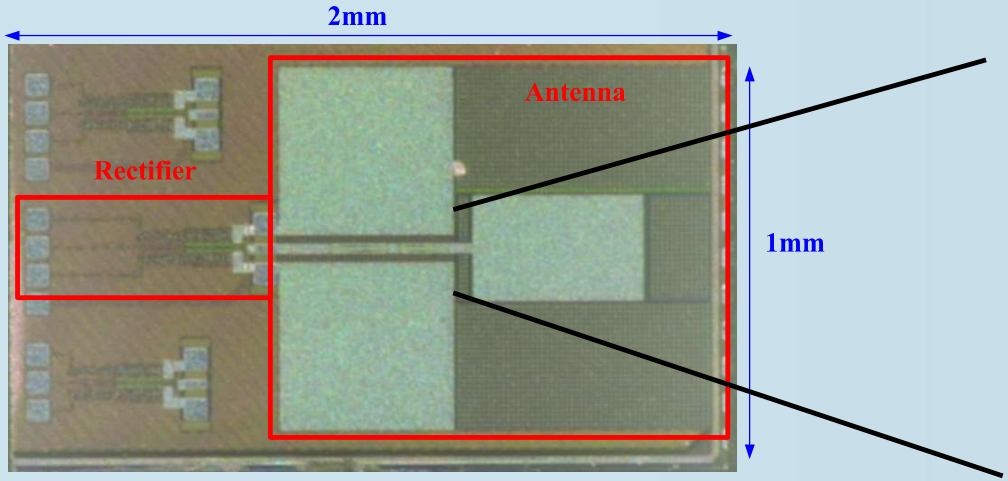
Dual-band antenna loaded with AMC plane

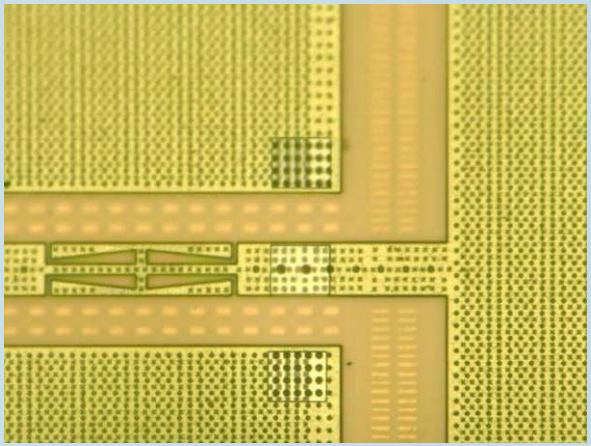
Antenna with three perpendicular polarizations

S. Yan, P.J. Soh and G.A.E. Vandenbosch, "Compact All-textile Dual-band Antenna Loaded with Metamaterial Inspired Structure," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 1486-1489, 2015. (Invited Paper)
S. Yan, P.J. Soh and G.A.E. Vandenbosch, "Low-profile dual-band textile antenna with artificial magnetic conductor plane", IEEE Transactions on Antennas and Propagation, vol. 62, no. 12, pp. 6487-6490, Dec. 2014.
S. Yan, and G.A.E. Vandenbosch, "Wearable Antenna with Tripolarization Diversity for WBAN Communications," IET Electronics Letters, vol. 52, no. 7, pp. 500-502, Apr. 2016.

Antenna design @ TELEMIC / MICAS

160 GHz on-chip rectenna of 2 x 1 mm^2

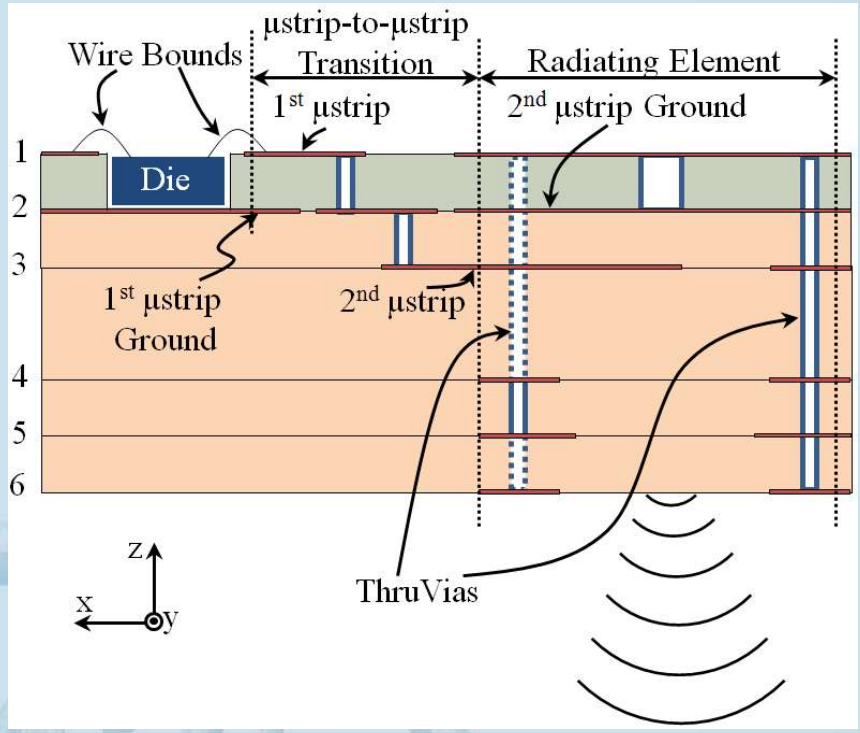


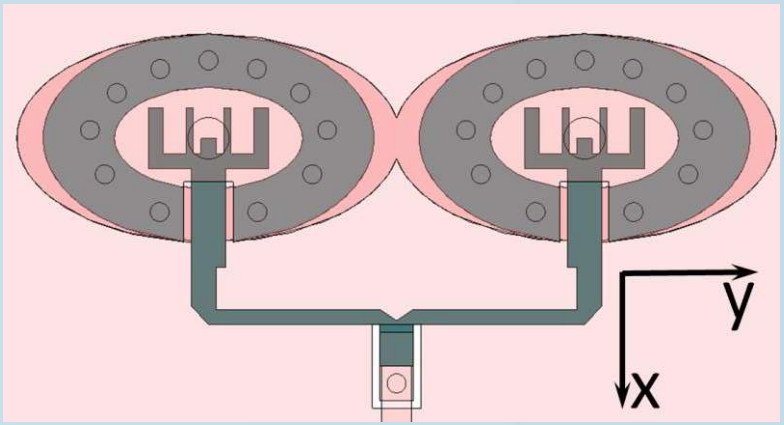


Challenges: technology, measurements,…

Antenna design: mm waves (with IMEC)

Millimeter-wave Horn-Type Antenna-in-Package in a Teflon-based Multilayer PCB Technology



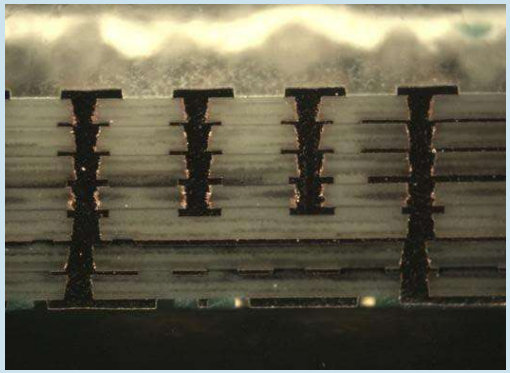


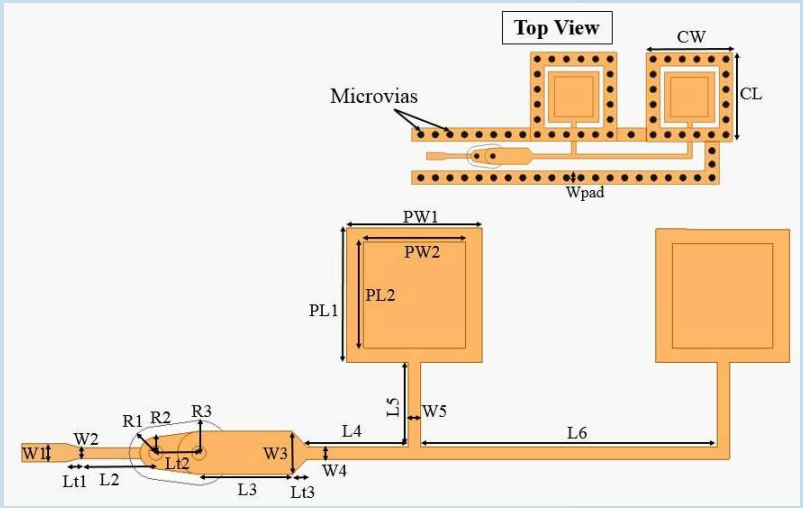
A. Enayati, G. A. E. Vandenbosch, and W. De Raedt, "Millimeter-wave horn-type antenna-in-package fabricated in a teflon-based multilayer PCB technology", IEEE Trans. Antennas Propagat., Vol. 61, No. 4, April 2013.

Challenges: technology, topology, measurement,…

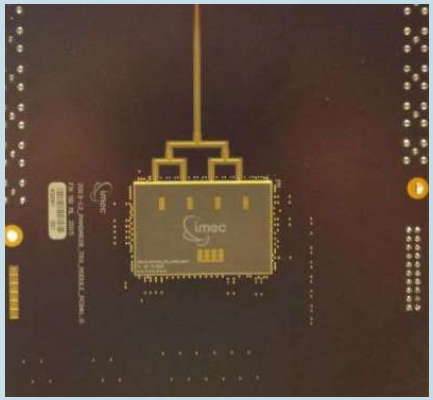
Antenna design: mm waves (with IMEC)

Millimeter Wave Cavity Backed Microstrip Antenna Sub-Array for 79 GHz Radar Applications, PIER, Vol. 158, 2017.





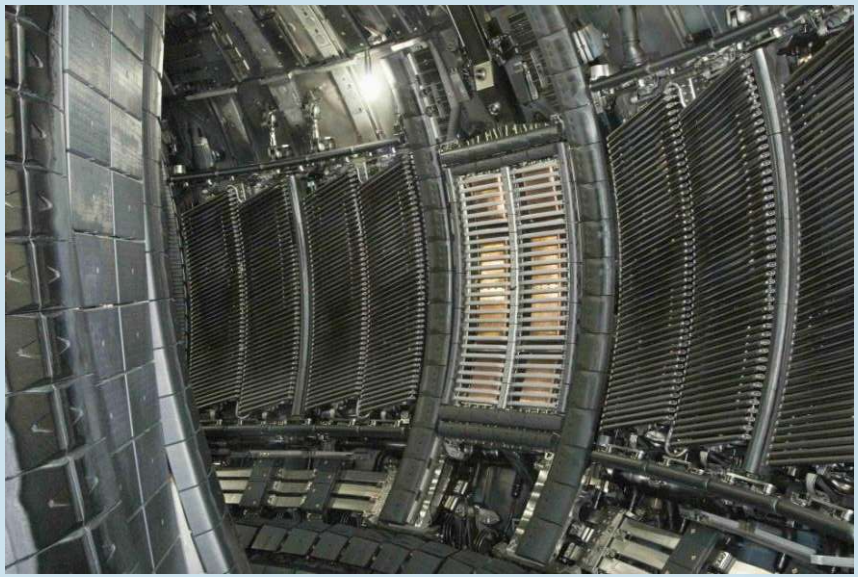
Any-Layer Technology:
- micro-vias
- very low cost

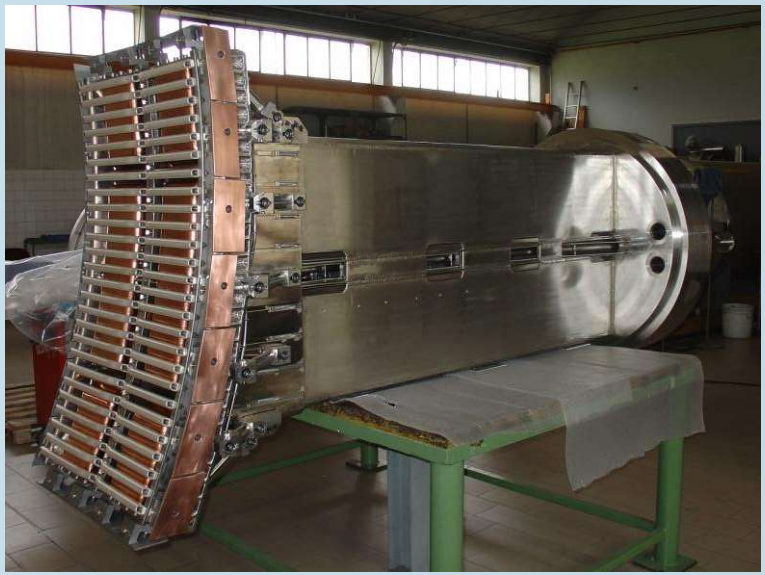


Antenna design: mm waves

- SILIKA = project within Marie-Curie Innovative Training Network Action of European Union
- SILIKA deals with “Silicon-based massive MIMO antenna systems for new telecommunication services”
  - Cooperation between TU Eindhoven (Netherlands), Chalmers (Sweden), KU Leuven (Belgium)
  - 12 “industrial” PhDs
  - Also In cooperation with industry:
    - NXP Semiconductors
    - Ericsson AB
    - Orban Micrwave Products NV
    - Saab Microwave Systems AB
    - Quamcom Research and Technology
    - ASTRON
    - TNO

Antenna design: nuclear fusion



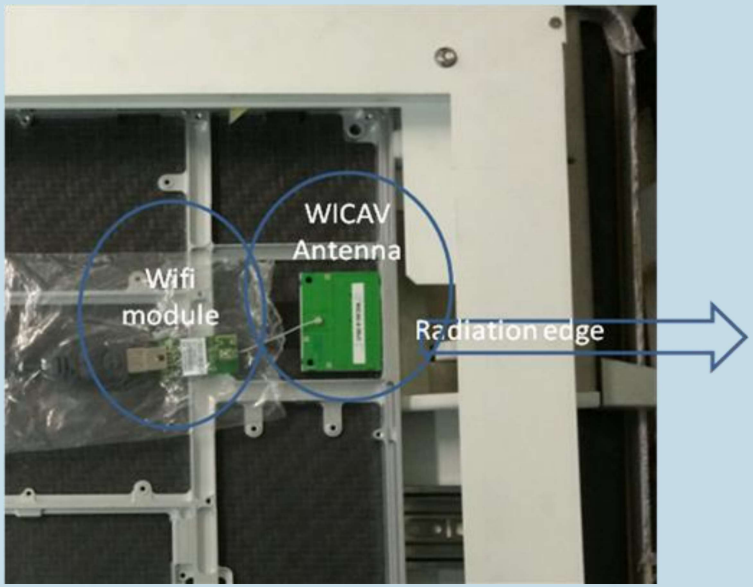


high power antennas for nuclear fusion (20 MW)

Challenges: modeling plasma (Green's functions), topology

Antenna design: for industry

A Dual Band SRR-Loaded Cavity Antenna Embedded within Multiple Metallic Enclosures



P. J. Soh, S. Yan, H. Xu, and G. A. E. Vandenbosch, "A Dual Band SRR-Loaded Cavity Antenna Embedded within Multiple Metallic Enclosures", IEEE Trans. Antennas Propagat., May 2015.

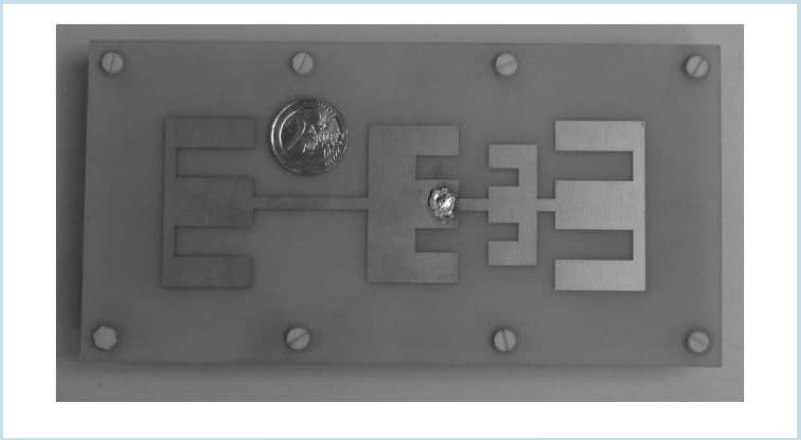
Antenna design: for industry

RFID loop antenna to embedded within clothing in metal locker

V. Volski and G. A. E. Vandenbosch, "Design of a loop antenna for an RFID system installed in a metal locker", IEEE Trans. Antennas Propagat., EuMICT, 25-26 March 2010, Ghent, Belgium.

Challenges: environment

highly compact WLAN antenna



Z. Ma, V. Volski, and G. A. E. Vandenbosch, "The design of a highly compact low-cost and strongly coupled 4 element array for WLAN", IEEE Trans. Antennas Propagat., March 2011.

Challenges: size, topology, cost, …

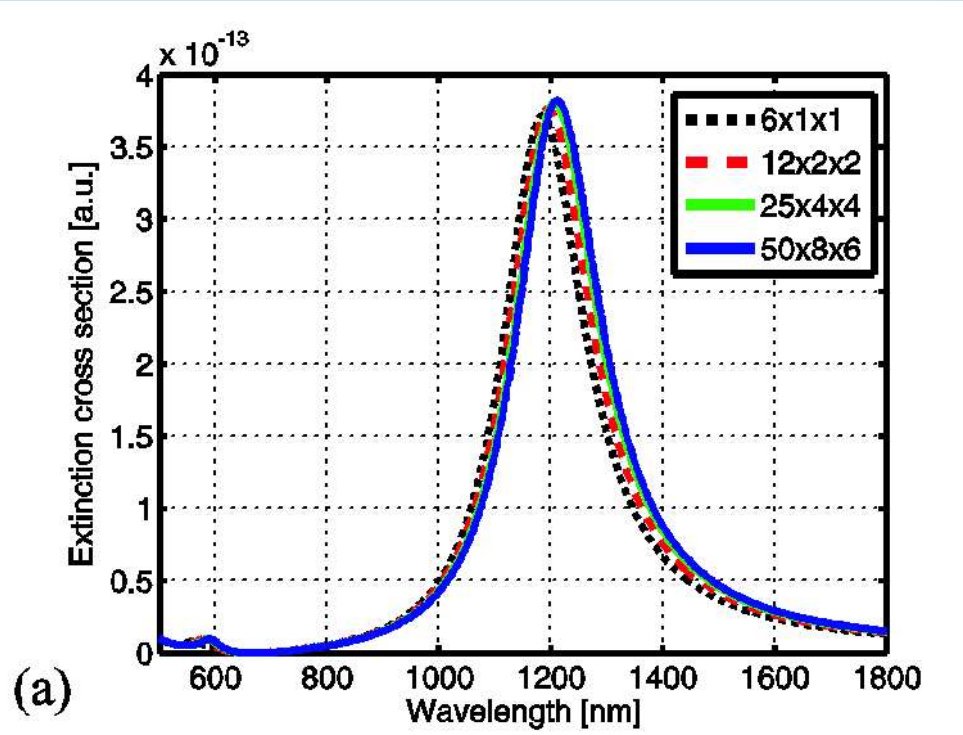
Antennas @ IR & optical frequencies

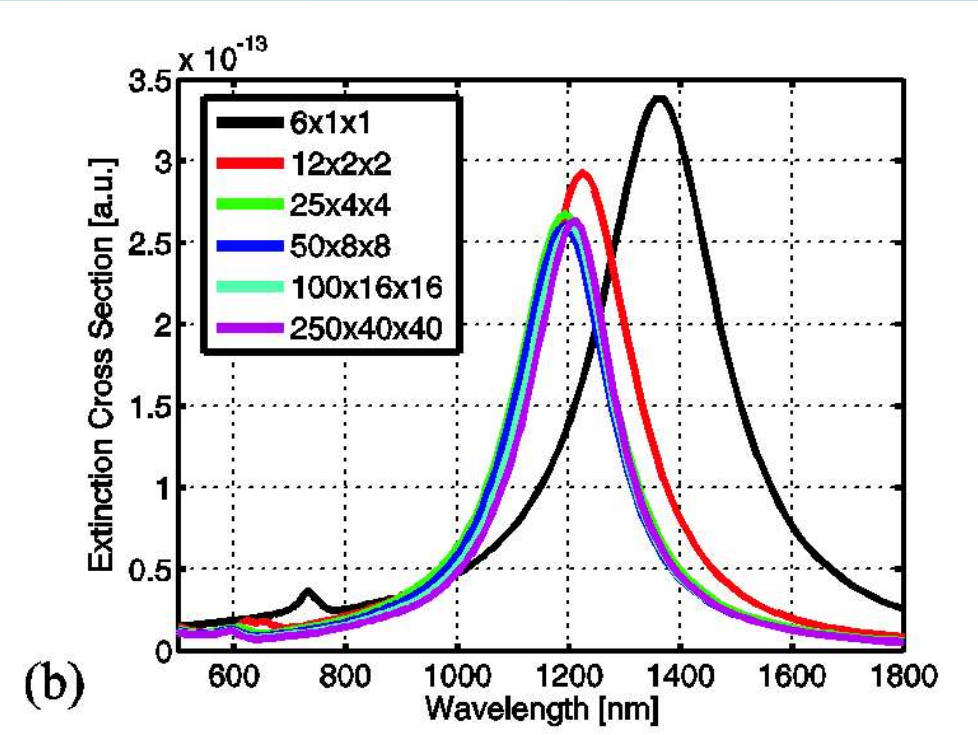
- Maxwell's laws are linear …
  - higher frequency → smaller size
- Question 1: Does classical electromagnetism, as it is used by engineers, i.e. based on these laws, still hold for structures of dimensions down to a few 100 atoms … probably yes …
- Question 2: What is the accuracy ? What are the discrepancies with rigorous Quantum Physics ?
- Question 3: BRIDGING THE COMPUTATIONAL GAP …

- **VERY "HIGH PROFILE" RESEARCH FIELD**

Nano-antennas: modeling

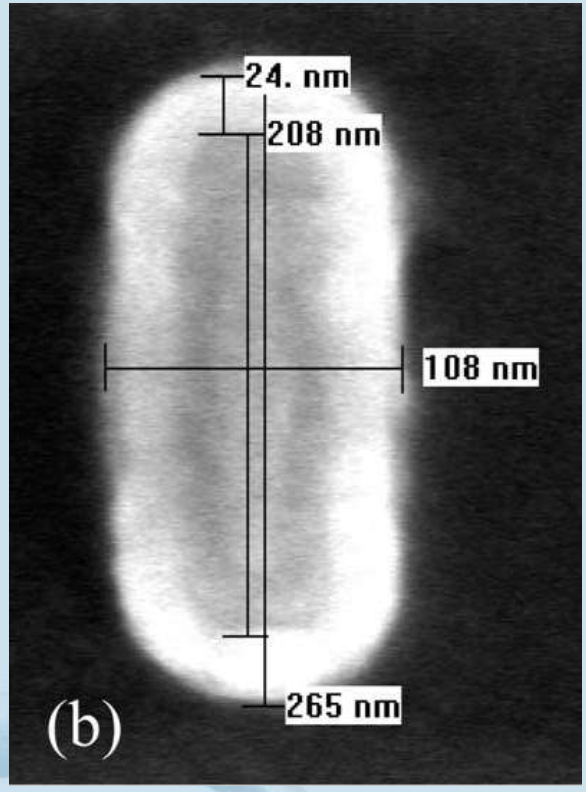
- At this moment, as far as we know, MAGMAS is the **only** Method of Moments **framework** suitable for IR and optical frequencies

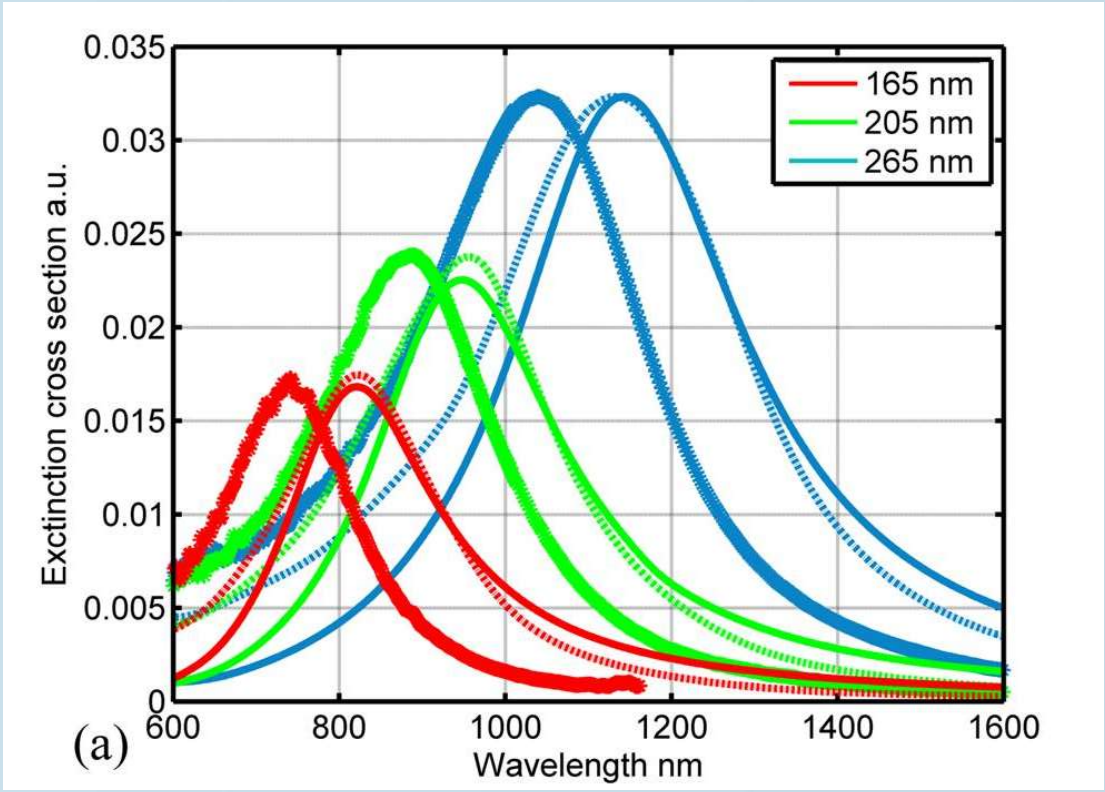




Extinction cross section of 250 nm x 40 nm x 40 nm gold monomer on substrate with n=1.5: a) MAGMAS 3D (V-MoM), b) Lumerical (FDTD).

Nano-antennas: analysis / measurement



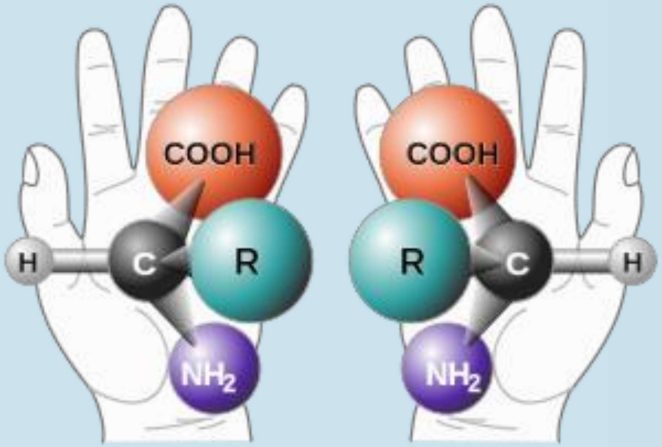


G. A. E. Vandenbosch, V. Volski, N. Verellen, and V. V. Moshchalkov, ”On the use of the method of moments in plasmonic applications”, Radio Science, Vol. 46, No. 5, Oct. 2011.

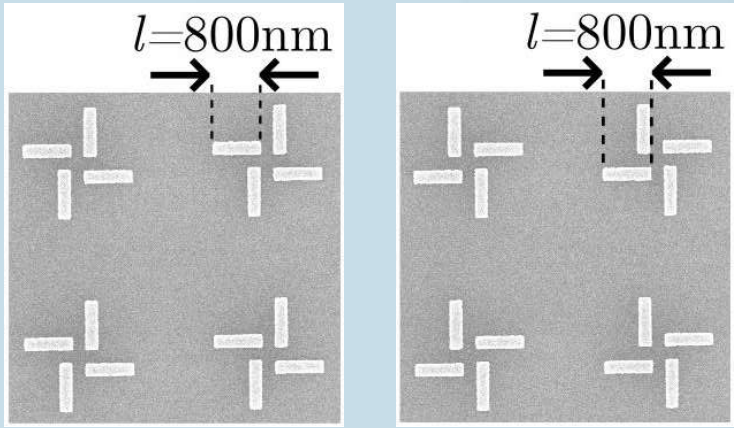
F. Pelayo G. De Arquer, V. Volski, N. Verellen, G. A. E. Vandenbosch, and V. V. Moshchalkov, “Engineering the input impedance of optical nano dipole antennas: materials, geometry and excitation effect”, IEEE Trans. Antennas Propagat., Vol. 59, No. 9, pp. 3144-3153, Sep. 2011.

Molecule Inspired Nanoantennas

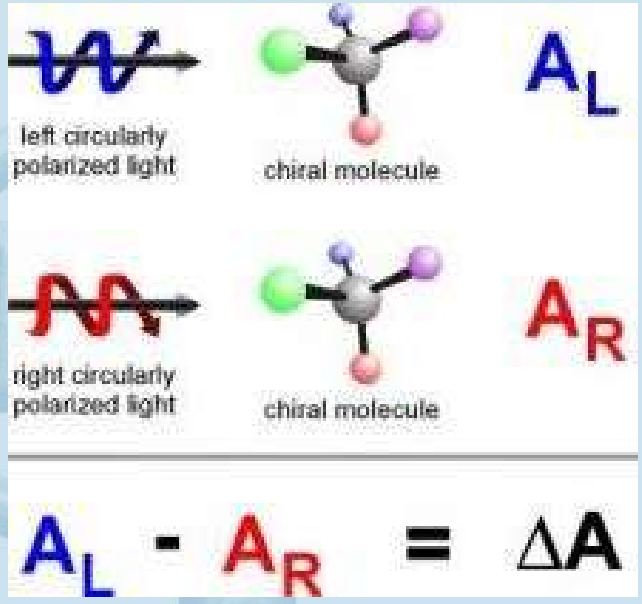
Chiral Molecules & Hands



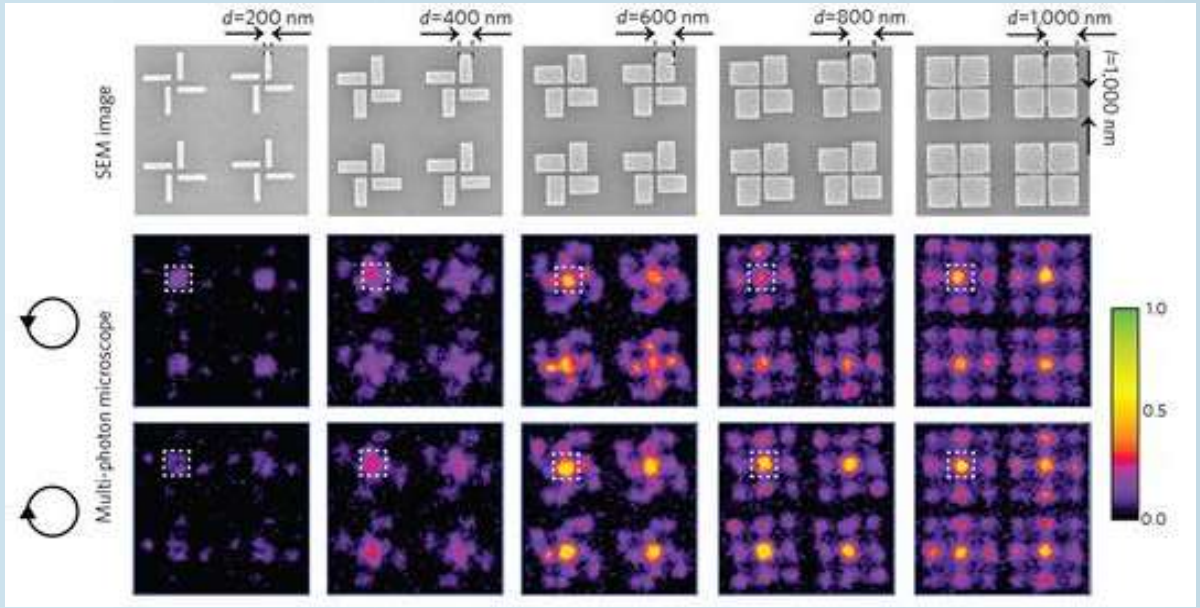
Chiral Structure



Circular Dichroism



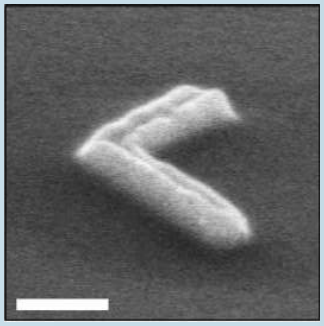
Nanoscale Replica



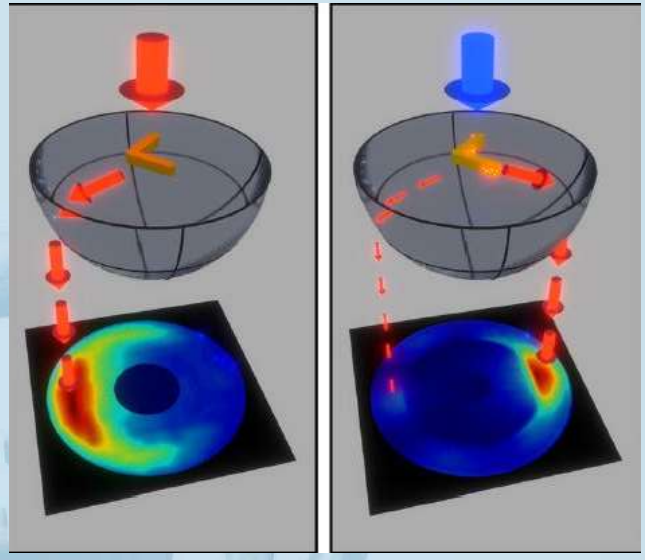
Microwave Inspired Nanoantennas (II)

Corner Reflector Antenna

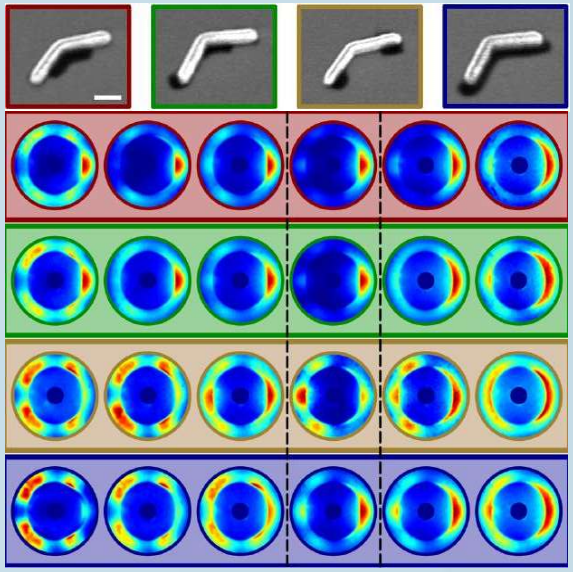
V Structure



Directional Emission



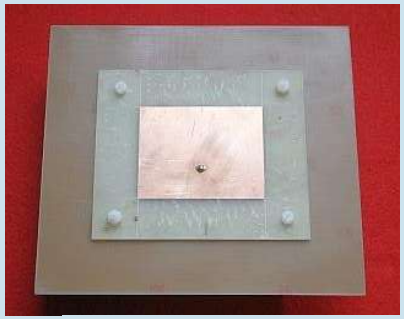
Tuning the Directional Emission



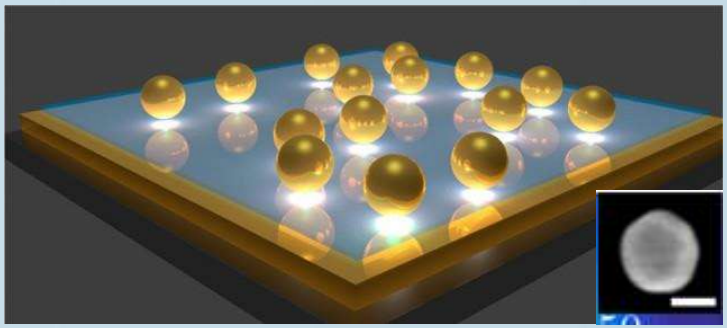
D. Vercruysse et al., "Directional Fluorescence Emission by Individual V-antennas Explained by Mode Expansion", ACS Nano, Vol. 8, No. 8, pp. 8232-8241, Aug. 2014.

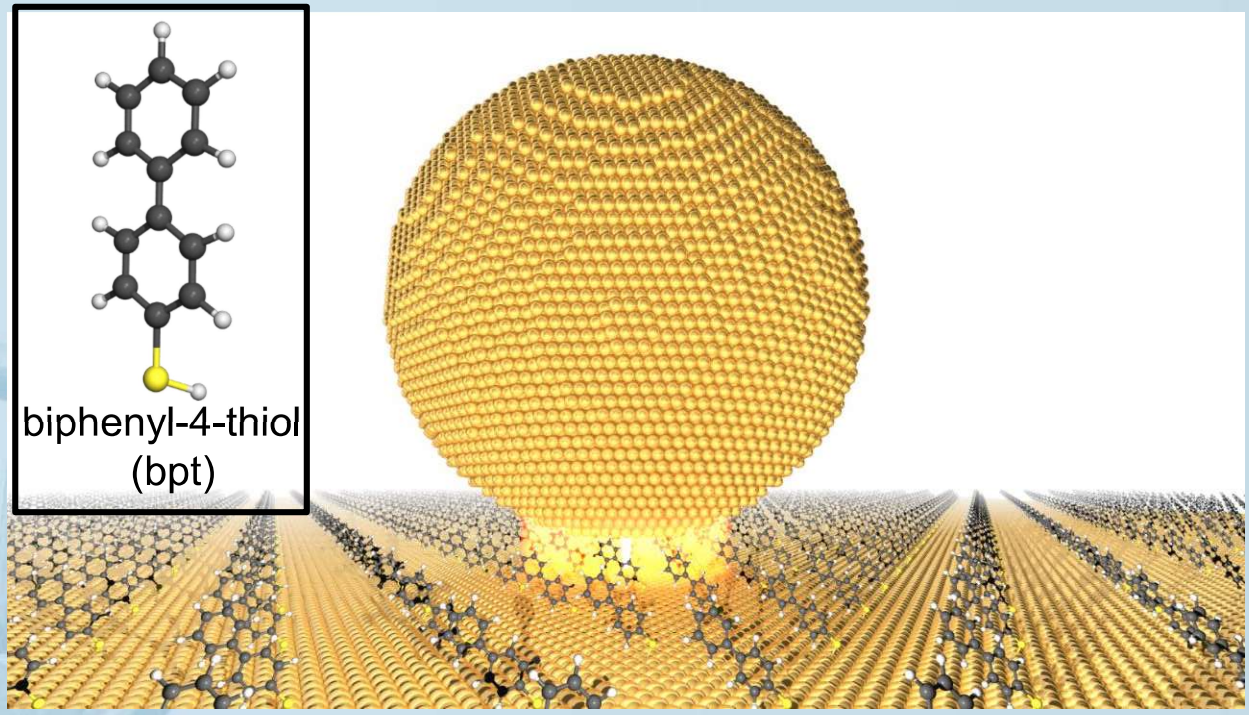
Microwave Inspired Nanoantennas (III)

Patch Antenna



Nanoparticle-on-Mirror Structure

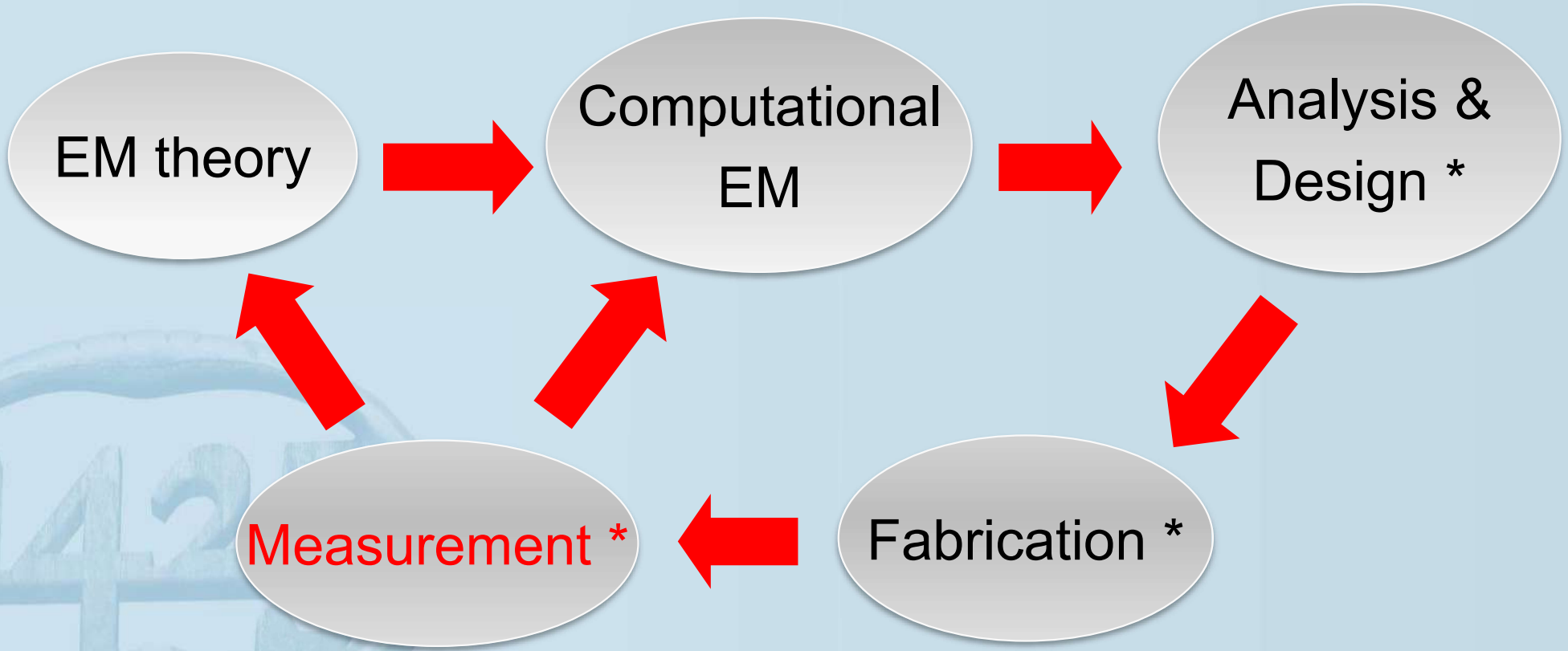




R. Chikkaraddy, X. Zheng, F. Benz, L. Brooks, B. de Nijs, C. Carnegie, M.-E. Kleemann, J. Mertens, R. W. Bowman, G. A. E. Vandenbosch, V. V. Moshchalkov, and J. J. Baumberg, "How ultranarrow gap symmetries control plasmonic nanocavity modes: from cubes to spheres in the nanoparticle-on-mirror", ACS Photonics, Vol. 4, No. 3, pp. 469-475, Feb. 2017.

Radiation and antenna research

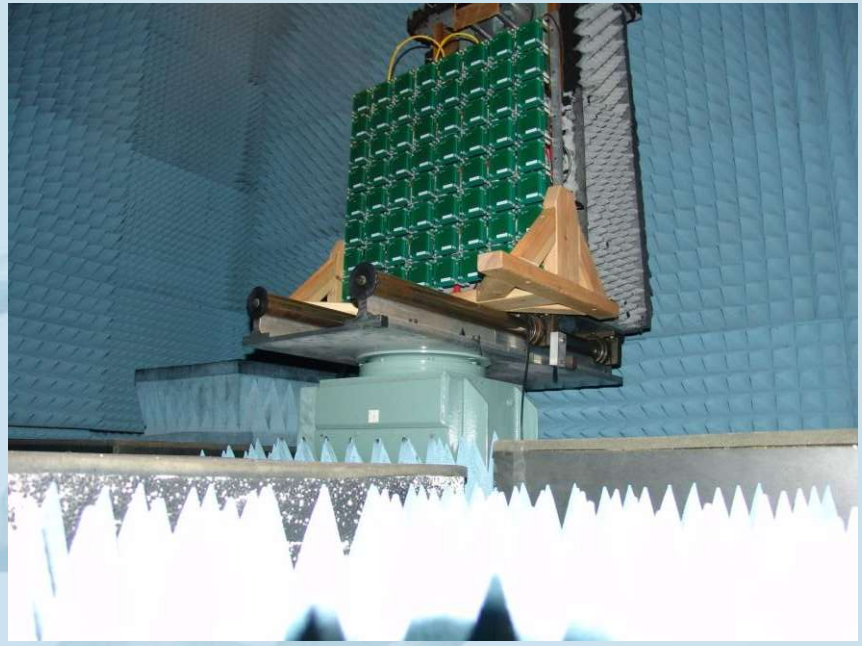
Fields of research and interactions



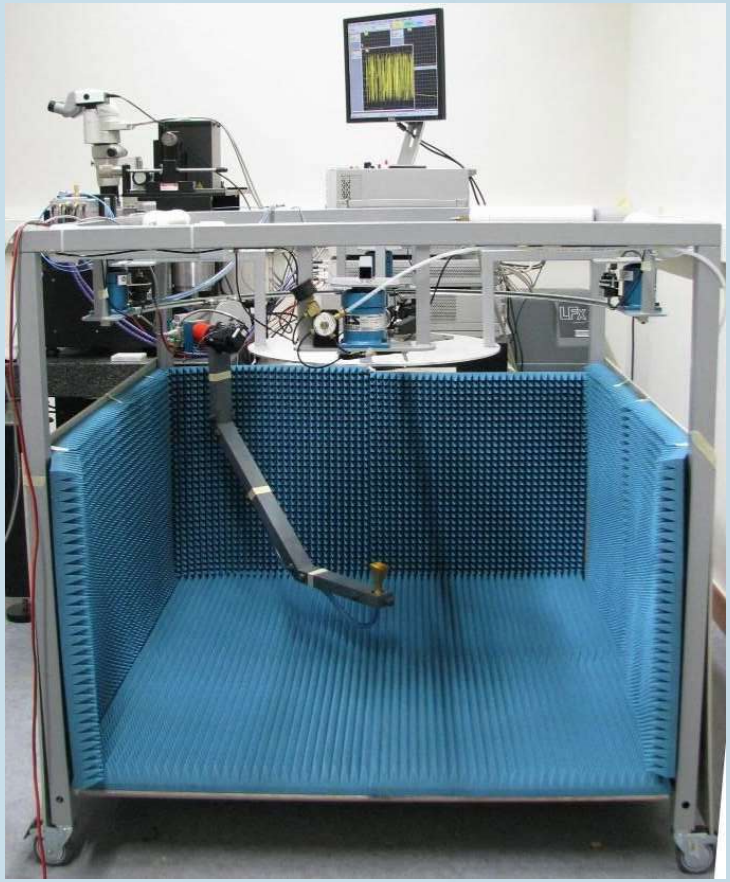
* cooperation with IMEC

Radiation measurements @ TELEMIC

polarisation over azimuth positioners and planar near field scanner in anechoic 10 m room for coaxially fed antennas)

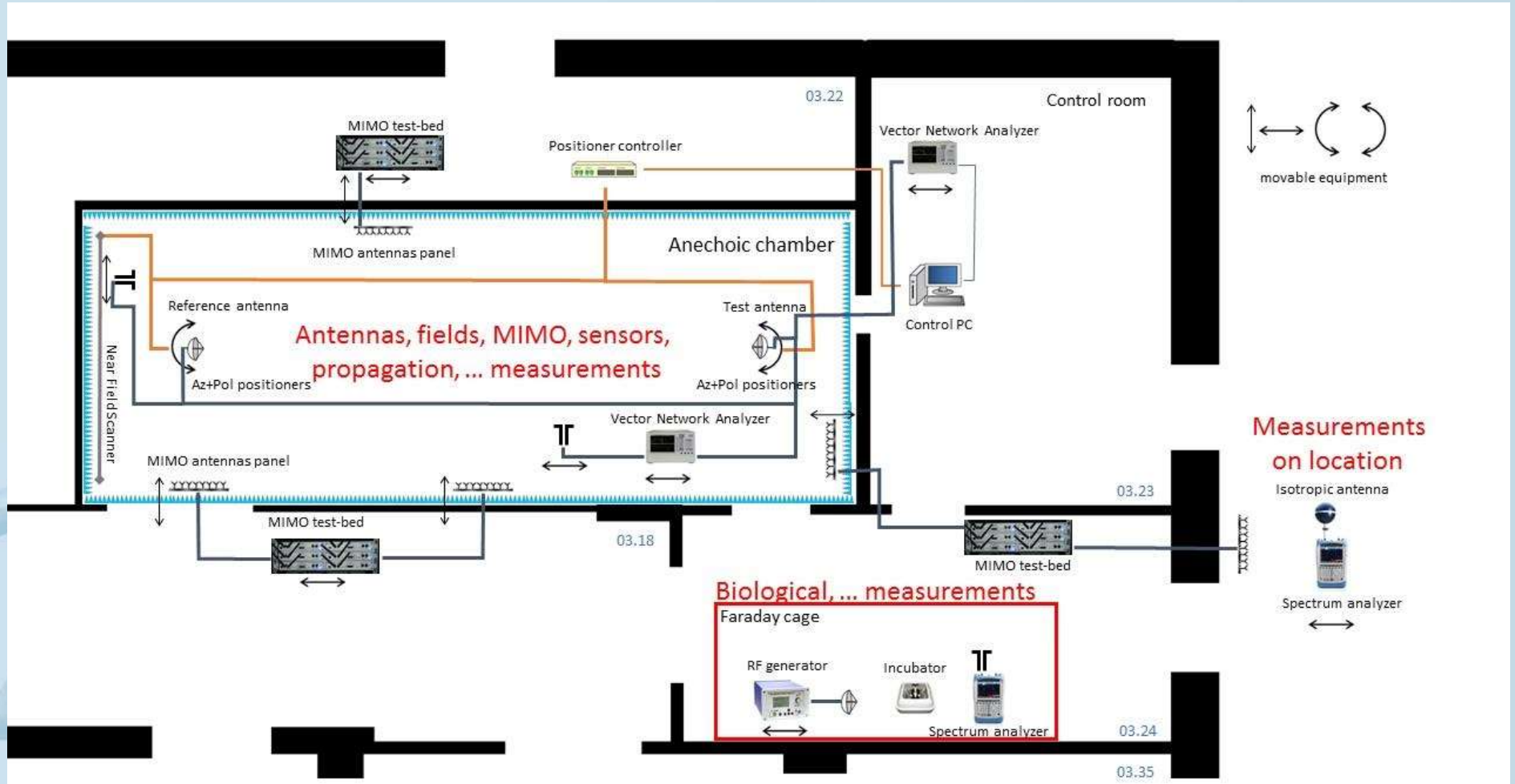


OWAMS: On Wafer Antenna Measurement System (> 60 GHz)



Ph.D. Karim M. Aghdam

Radiation measurements @ TELEMIC



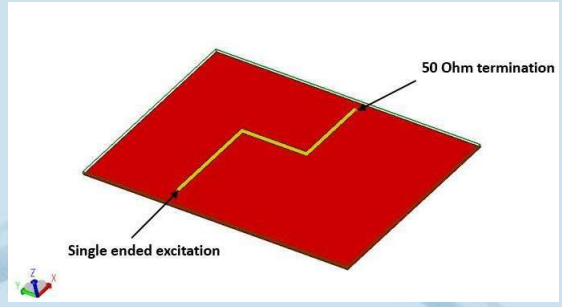
Multifunctional flexible non-ionizing electromagnetic radiation measurement facility

Near Field to Far Field Transformations for EMC and Antennas

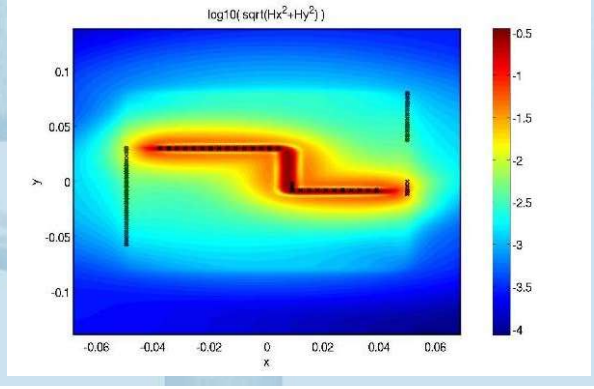
Working mechanism:

+ Near field scan data
+ Auxiliary dipoles (ADs)
- Near field simulated data (ADs)

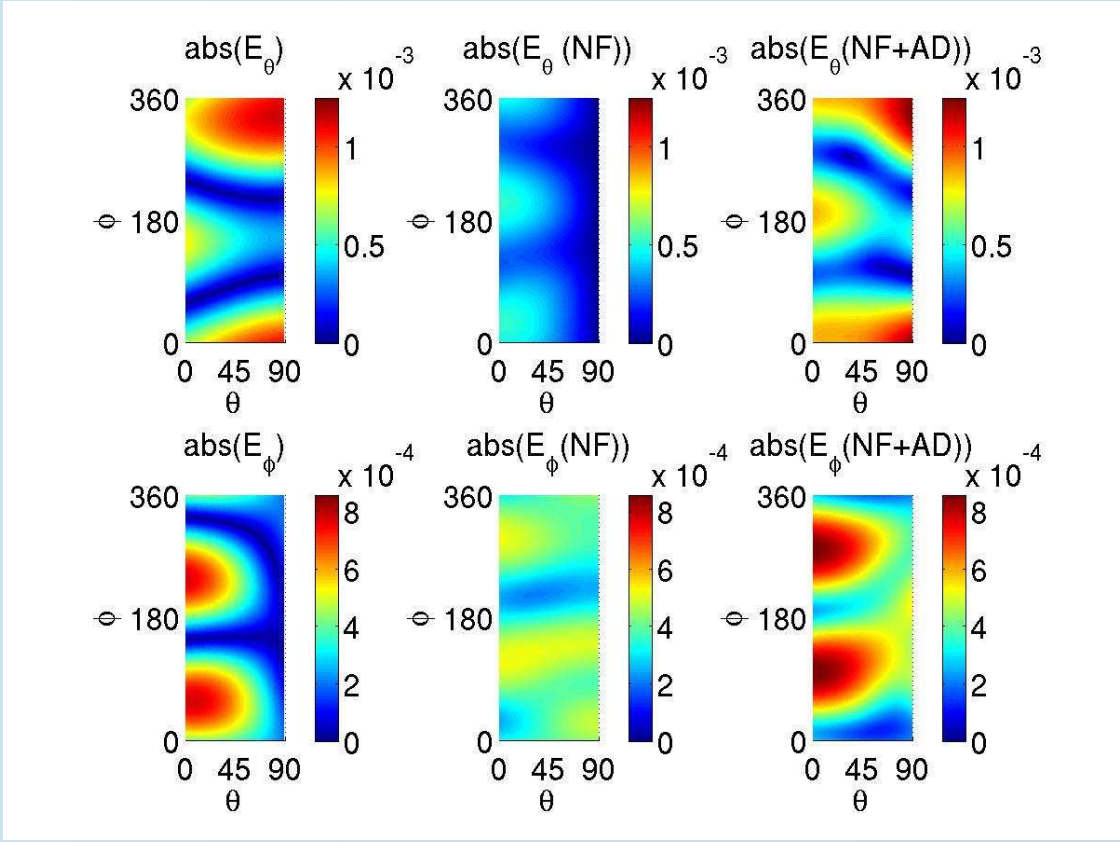
Screenshot



Scan data + updated ADs



Far Field Patterns (200 MHz)

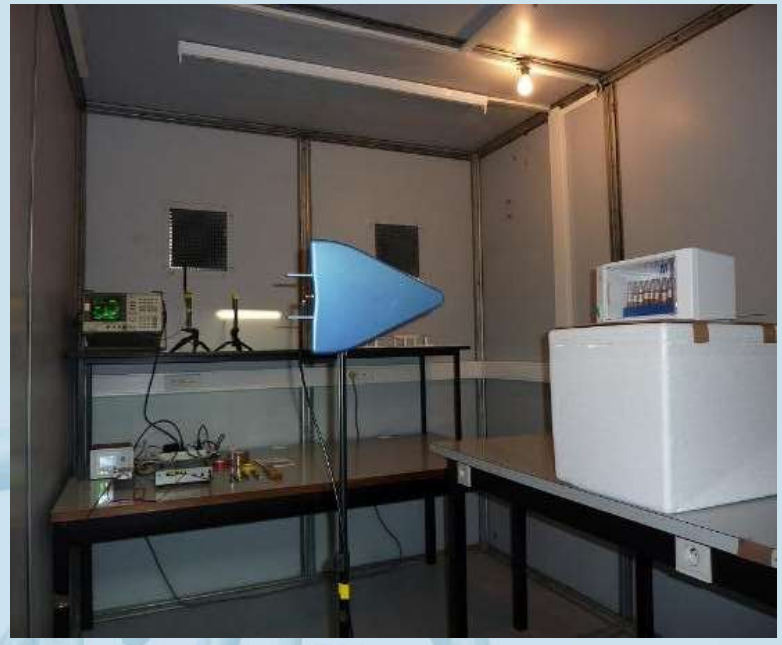


V. Volski, S. Yan, T. Claeys, G. A. E. Vandenbosch, D. Pissoort, “Auxiliary Dipoles to Compensate for the Finite Size of the Planar Scanning Area in Near-to-Far-Field Transformations”, IEEE Trans. EMC, Dec. 2015.

T. Claeys, V. Volski, G. A. E. Vandenbosch, D. Pissoort, “Near-Field Edge Extrapolation Using Auxiliary Dipoles to Improve Probe Compensation”, IEEE Trans. EMC, April 2017.

NIR exposure measurements

Lab measurements

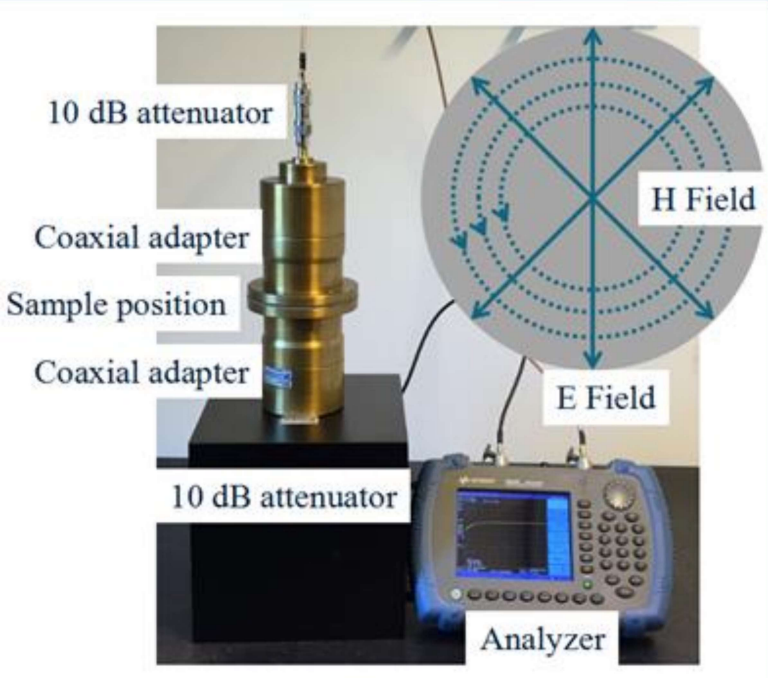


In-situ measurements

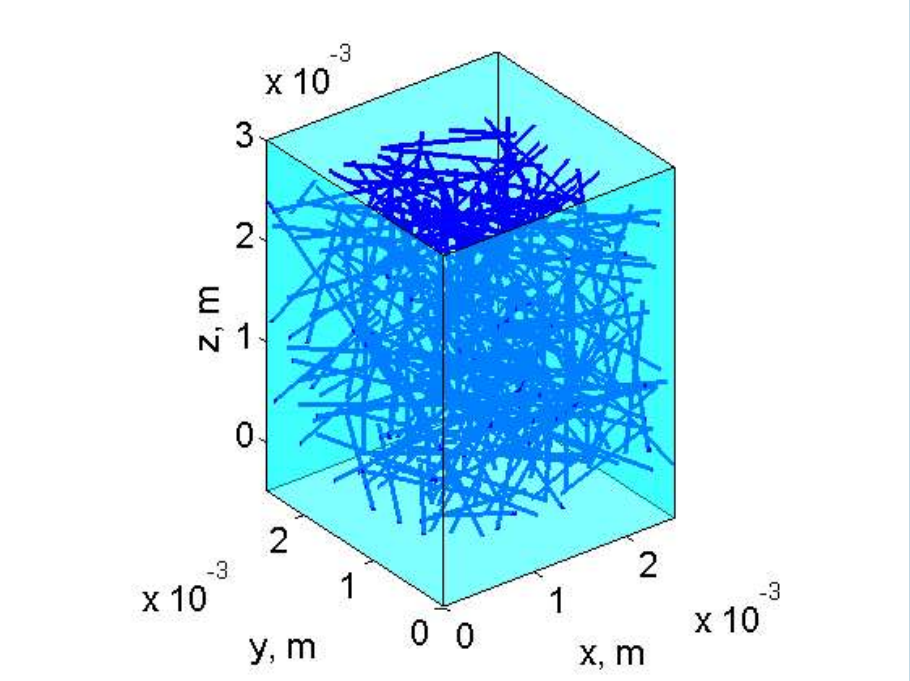
M.C. Cammaerts, G. A. E. Vandenbosch, V. Volski, “Effect of Short-Term GSM Radiation at Representative Levels in Society on a Biological Model: The Ant Myrmica sabuleti”, Journal of Insect Behavior, July 2014.

Shielding measurements and modeling of fiber assemblies and conducting textiles

Shielding measurements



Arbitrarily oriented fibers



V. Volski, G. A. E. Vandenbosch, “Full-wave electromagnetic modelling of fabrics and composites”, Composites Science and Technology, 2009

S. Tezel, Y. Kavusturan, G. A. E. Vandenbosch et al, “Comparison of electromagnetic shielding effectiveness of conductive single jersey fabrics with coaxial transmission line and free space measurement techniques”, Textile Research Journal, 2014

Conclusions

- Overview of radiation / antenna research activities at KU Leuven, Leuven, Belgium
- 1 full professor, 3 post-docs, and ca. 20 PhDs are active in the fields discussed
- Many research fields and lots of cooperation with other groups all over the world